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CASE REPORT

A NON-OPERATIVE APPROACH TO THE MANAGEMENT OF CHRONIC EXERTIONAL COMPARTMENT SYNDROME IN A TRIATHLETE: A CASE REPORT

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ABSTRACT

Background & Purpose: Chronic Exertional Compartment Syndrome (CECS) causes significant exercise related pain secondary to increased intra-compartmental pressure (ICP) in the lower extremities. CECS is most often treated with surgery with minimal information available on non-operative approaches to care. This case report presents a case of CECS successfully managed with physical therapy.

Study Design: Case report

Case Description: A 34-year-old competitive triathlete experienced bilateral anterior and posterior lower leg pain measured with a numerical pain rating scale of 7/10 at two miles of running. Pain decreased to resting levels of 4/10 two hours post exercise. The patient was diagnosed with bilateral CECS with left lower extremity ICP at rest measured at 36 mmHg (deep posterior), 36-38 mmHg (superficial posterior), and 25 mmHg (anterior). Surgery was recommended.

Interventions: The patient chose non-operative care and was treated with physical therapy using the Functional Manual Therapy approach aimed at addressing myofascial restrictions, neuromuscular function and motor control deficits throughout the lower quadrant for 23 visits over 3.5 months.

Outcomes: At discharge the patient had returned to running pain free and training for an Olympic distance triathlon. The Lower Extremity Functional Scale improved from 62 to 80. The patient reported minimal post exercise tightness in bilateral lower extremities. Left lower extremity compartment pressure measurements at rest were in normal ranges measuring at 11 mmHg (deep posterior), 8 mmHg (superficial posterior), 19 mmHg (anterior), and 10 mmHg (lateral). Three-years post intervention the patient remained pain free with a Global Rating of Change of 6.

Discussion: This case report describes the successful treatment of a triathlete with Functional Manual Therapy resulting in a return to competitive sports without pain.

Level of Evidence: Level 4

Key Words: Chronic Exertional Compartment Syndrome, fasciotomy, physical therapy, running

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BACKGROUND & PURPOSE

Chronic Exertional Compartment Syndrome (CECS) is a debilitating condition characterized by severe pain in the lower extremities (LE).[1-4] It is defined as a condition of pain caused by exercise and often relieved by rest.[5] If physical activity is continued the symptoms of CECS are believed to persist over time.[6] CECS is most commonly seen in recreational and elite athletes, those involved in team sports requiring running, and in military recruits.[1,5,7-10] The prevalence of CECS in the general population is unknown as many athletes reduce activity and do not seek medical care.[11] While it is known that individuals suffering from CECS present with increased intracompartmental pressure (ICP),[1,5,8,12] the etiology remains uncertain. The previous theory that the pain is caused by muscle ischemia from increased ICP has been refuted.[13,14] Some researchers have proposed that pain is caused by increased stretch and tension in fascial tissues with possible compression of sensory nerves.[15,16] Additional symptoms may include numbness and tingling in dermatomal distributions of the nerve within that compartment and weakness of the affected muscles.[1]

CECS can occur in the upper extremity but 95% of occurrences are in the LE.[5,8] Most authors report four distinct lower leg compartments involved in CECS: anterior, lateral, superficial posterior, and deep posterior compartments with 95% of cases occurring in the anterior and lateral compartments.[1,2,8,17,18] It has been reported that 87% of patients with CECS are involved in sports, with runners accounting for 69% of cases.[8] Incidence is divided almost evenly between genders, with a median age at onset of 20 years.[2,8] Pain is frequently predictable following a specific duration and intensity of exercise and symptoms are bilateral in 70-80% of cases.[1,5,7,19,20] CECS can go undiagnosed with a typical delay of 22 months and is often misdiagnosed as symptoms commonly subside with rest.[1,21] Differential diagnosis of CECS include medial tibial stress syndrome, stress fracture, fascial defects, nerve entrapment syndrome, popliteal artery entrapment syndrome, and claudication.[1,5] The gold standard for definitive diagnosis is ICP measure at rest and at five minutes following exercise through a catheter connected to a manometer for a measure of intra-compartmental pressure.[1,14,15,22-26] Less invasive diagnostic tests, often used as part of the differential diagnosis, include MRI, infrared spectroscopy, ultrasound imaging, and Thallium 201 chloride scintigraphy with SPECT scanning however these have not been deemed sufficient for definitive diagnosis.[25,27-29] The most commonly used pressure diagnostic criteria for CECS is as follows: pressure in any of the compartments greater than or equal to 15mmHg pre-exercise; elevation to 30mmHg one-minute post-exercise; or elevation to 20mmHg five minutes post-exercise.[12]

The paucity of evidence for non-operative care often drives athletes to quit their sport or opt for a compartmental fasciotomy, which is still the only evidence based approach to the management of CECS.[1,8,10,30,31] While surgery is reported to have an 80% success rate, the 11-13% complication rate includes infection, hemorrhage, nerve damage, deep vein thrombosis, vascular injury, skin breakdown, sensory deficits, nerve entrapment, and complex regional pain syndrome.[1,8,10,30-33] In addition, a 6-11% rate of recurrence has been reported following surgical release of CECS.[1,14,34]

Several researchers evaluating the effect of non-operative treatment on CECS have demonstrated less than optimal success in reduction of long-term pain with most cases resulting in a decrease in level of activity or surgery.[3,7,9,15,35-40] The most successful non-operative approach to treatment requires athletes to stop exercising or decrease the intensity of training. While this strategy leads to improvement, the symptoms tend to return when the athlete resumes exercising even if the return is gradual.[1,5,21] A change in running form to a forefoot running strategy has been reported to result in improvement in pain levels and compartment pressures in 12 runners, especially those with anterior compartment pain.[9,39] Massage resulted in short term symptomatic improvement in CECS with no significant reduction in compartment pressures and symptoms.[41] The use of arch supports to change the biomechanical load on the LE has been tried without success.[34] Minimal improvement has been noted following traditional physical therapy (PT) interventions such as stretching; modalities such as ice, heat or ultrasound; therapeutic exercises; strengthening; and anti-inflammatory medications.[5,21] While it appears that CECS patients may have some improvement following manual therapy or functional training, alone these approaches do not appear to be sufficient in assisting the patient to full recovery. The use of a non-operative approach to treatment of CECS would be beneficial if it could prevent the risk, complications and costs related to surgical intervention. No cases exploring the effects of a comprehensive rehabilitation program addressing all aspects of the movement system[42] in the management of CECS have been published to date.

The purpose of this case report is to describe a non-operative, comprehensive approach to physical therapy, Functional Manual Therapy (FMT),[43] in the treatment of a competitive tri-athlete with bilateral CECS who did not desire surgery. In the absence of a successful non-operative approach to the management of CECS, no randomized controlled and long-term trials investigating a comprehensive, non-operative management approach have been conducted making a case report the most appropriate place to start.[7]

CASE DESCRIPTION

Subject History

The subject was a 34-year-old competitive tri-athlete who had been competing for six years. He presented with a 12-month history of progressive leg pain, tenderness, swelling and tingling in the posterior aspect of both legs and occasionally anteriorly. Symptoms were provoked with running and, to a lesser degree, with cycling. At the time of the initial PT examination, the subject was limited to running a maximum of two miles, two to three days per week, due to 7/10 bilateral pain on a numerical pain rating scale (NPRS) and tingling. The pain returned to a baseline level of 4/10 within two hours of running cessation. The subject had undergone a course of PT with another therapist consisting of modalities, massage, custom orthotics, stretching, and strengthening for three months with no change in symptoms. He continued to report persistent soreness and tingling in both the anterior and posterior lower legs.

Medical records indicated that ICP measures on the left side had been previously assessed. The treating physician chose to obtain pressures only on the left LE, despite bilateral presentation, in order to minimize the number of invasive testing procedures. Pre-exercise ICP measurements were taken of the anterior, deep posterior and superficial posterior compartments (Table 1). With all ICP measures higher than 15mmHg at rest, and the same symptoms bilaterally, the subject was diagnosed with CECS and bilateral fasciotomy was recommended. The subject opted against surgery to pursue another

Table 1. *Leg compartment Intercompartmental Pressure measures*

Leg Compartment	Baseline*	4 months post discharge*	
		At rest	Post-exercise (within 1 minute)
L Anterior	25 mmHg	19 mmHg	22 mmHg
L Lateral	not measured†	10 mmHg	18 mmHg
L Superficial Posterior	36-38 mmHg	8 mmHg	12 mmHg
L Deep Posterior	36 mmHg	11 mmHg	22 mmHg
R Anterior	not measured†	15 mmHg	20 mmHg
R Lateral	not measured†	9 mmHg	17 mmHg
R Superficial Posterior	not measured†	11 mmHg	20 mmHg
R Deep Posterior	not measured†	12 mmHg	22 mmHg

*A medical decision was made to limit pre-intervention measures to the left lower extremity due to the invasive nature of the procedure. The assumption was made that a bilateral diagnosis would be applied given that symptoms were of equal intensity in both LE's.
†Given the reduction in symptoms and the lack of medical necessity for follow ICP measures, Stryker catheter measures were not taken following the intervention period.
Abbreviations: L, left; R, right

Table 2. *Passive Range of Motion and Muscle Strength*

Range of Motion (ROM)				
	Baseline Week 1 Session 1		Post Intervention Week 14 Session 23	
	left	right	left	right
Hip Extension	12°	10°	15°	18°
Hip IR	30°	30°	35°	38°
Hip ER	30°	30°	40°	44°
Hip Abduction	30°	30°	35°	35°
Ankle DF	15°	15°	20°	22°
Ankle PF	45°	45°	48°	50°
Ankle Inversion	35°	35°	38°	40°
Ankle Eversion	15°	18°	20°	22°
Manual Muscle Testing (MMT)				
	Baseline Week 1 Session 1		Post Intervention Week 14 Session 23	
Hip Abductors	3-/5	3-/5	4+/5	5-/5
Ankle Dorsiflexors	3+/5	3+/5	5/5	5/5
Ankle Evertors	4-/5	4-/5	5/5	5/5

Abbreviations: IR, internal rotation; ER, external rotation; DF, dorsiflexion; PF, plantarflexion.

course of PT with the goal of returning to pain free competitive running. The subject was informed and was in support of data in his case being submitted for publication.

Systems Review

A systems review and past medical history revealed no limitations or concerns beyond the musculoskeletal system with limitations in range of motion (ROM) and strength throughout the lower quadrant. (Table 2)

Clinical Impression #1

In the absence of a significant past medical or surgical history and any other signs or symptoms, the subjective presentation was consistent with CECS. The subject presented with no red flags for tibial fracture and nerve or vascular entrapment. The reproduction of symptoms with running, decrease in symptoms following rest, and intra-compartmental pressure measurements at rest meeting the diagnostic criteria for CECS, further supported this diagnosis. The subject was deemed appropriate for a full physical therapy examination.

EXAMINATION/EVALUATION

Tests and Measures

The results of the initial examination can be found in Tables 2 and 3. The subject presented for the initial evaluation three months following medical diagnosis. During this period he remained unable to run secondary to pain. Anterior view of standing posture revealed that both tibias were externally rotated in relationship to the femur. During active squatting both knees deviated medially into a valgus position with absent dissociation of pelvic girdle motion from the lumbar spine resulting in excessive lumbar extension. In addition to limitations in ROM and strength, an observational gait analysis revealed noticeable pelvic girdle asymmetries between left and right in the transverse, frontal and sagittal planes. Bilateral early heel rise and a medial heel

Table 3. *Scores on Functional and Subjective Scales*

	Baseline Week 1 Session 1	Post Intervention Week 14 Session 23
LEFS	62	80
NPRS	4/10 at rest 7/10 after running	0/10 at rest and after running

Abbreviations: LEFS, Lower Extremity Functional Scale; verbal NPRS, numerical pain rating scale

whip during push off were also noted. The subject demonstrated inadequate feed-forward response including the inability to maintain standing alignment when challenged with a perturbation to the shoulder in the four diagonal directions when testing the lumbar protective mechanism.[44] While the validity and reliability of this perturbation test has not been established, the subject's inability to maintain upright against a challenge was interpreted as ineffective dynamic core stability in static standing and used only as an additional functional test. Since the patient had received a pair of custom foot orthotics from the previous physical therapist, an intervention often attempted in cases of CECS, the perturbations to the shoulder were also attempted with the custom foot orthotics in the shoe to assess their effect on the subject's functional stability. No changes in the subject's response to the test were noted possibly indicating that core feed-forward response was not affected by foot posture.

The subject was observed and video-recorded in the frontal and sagittal planes with a SONY Handycam (HDR-CX440) while running on a treadmill at 7.0 mph. He reported pain beginning at 30 seconds of running and increasing until the examination was terminated at 90 seconds due to pain increasing to 7/10.[45,46] The pain started in the posterior compartment of both LEs progressing to the anterior leg. Visual and video observation of the subject's running pattern (video analysis through the program Live from Siliconcoach) revealed bilateral heel strike running pattern, decreased left push off, shorter left stride length as measured by tibial shank angle, right femoral adduction at mid-stance with a corresponding left pelvic drop representing a positive Trendelenburg sign.

ROM and strength measures revealed limitations across the lower quadrant (Table 2). Ankle mobility was assessed by joint end-feel and the ability of muscles to lengthen or shorten when the ankle was moved passively. End-feel assessment is an integral part of the PT examination. A hard end feel may be indicative of joint dysfunction or soft tissue restriction and can help guide intervention.[46] Ankle mobility was found to be limited secondary to restricted talocrural joint mobility with a hard end-feel in posterior talar glide with tight gastrocnemius-soleus and posterior tibialis muscles. Restrictions with a hard end-feel were also noted with calcaneal medial and lateral glide on the talus, talus medial and lateral glide on the tibia, navicular inferior glide, and cuboid inferior glide. Soft tissue mobility of the plantar aspect of the foot was restricted with increased tension present during hallux extension. A hard end-feel was also noted in the posterior glide of the distal tibia on the talus. While no significant restrictions were present in the pelvic girdle complex, asymmetries in alignment and mobility of the coccyx, sacrum and innominates were noted. The seated slump test[47] was positive for neural tension in both LEs limiting passive knee extension with the lumbar spine in flexion and in extension. The slump test assesses limitations in knee extension range of motion secondary to mechano-sensitivity in neural tissues and has been shown to have excellent test-retest reliability (ICC = 0.93-0.96, SEM = 2.6°-3.3°).[48,49] The subject scored 62/80 in the Lower Extremity Functional Scale (LEFS) which is a valid measure for LE problems with excellent test-retest reliability ($r = 0.86$ to 0.94), a minimal clinically important difference (MCID) and a minimal detectable change (MDC) of 9 points each (90% CI)(Table 3).[50]

Clinical Impression #2

Examination findings of restricted ROM and strength combined with movement dysfunction across the lower quadrant and pain noted during running that decreased with cessation, in the absence of red flags for other conditions, further supported the diagnosis of CECS. The presence of articular, soft tissue, fascial and neural mobility restrictions throughout the lower quadrant was believed to be the cause of movement dysfunction noted during gait and while running. Based on the decreased stability in static standing, the observed running pattern and clinical experience, the therapist believed that the subject's decreased proximal stability control was also affecting distal mobility coordination during higher-level functional activities such as running. The decreased soft tissue and fascial extensibility evaluated in the gastrocnemius-soleus and posterior tibialis muscles and decreased mobility of the tibial-fibular interosseus membrane were believed to be contributing to decreased compartmental mobility during running. The asymmetries noted in the pelvic girdle were believed to contribute to neural-fascial tension possibly affecting the mobility of tissues during running. The working hypothesis was that mechanical dysfunctions of soft tissue, fascia and joint within the lower quadrant were affecting the gait and running pattern leading to weakness and movement dysfunction and an inability to run efficiently and pain free.

Prognosis

The subject was deemed a good candidate for physical therapy given his age, motivation, and active lifestyle. While supporting evidence for the non-operative management of CECS is limited,[40] the presence of mechanical, neuromuscular and motor control impairments throughout the lower quadrant appeared to be involved with the noted functional limitations making the subject a good candidate for a comprehensive approach to physical therapy including manual therapy, neuromuscular facilitation and motor control training. Discharge criteria included being able to run five miles pain free.

Intervention

The episode of care lasted 3.5 months during which the subject was seen 1-2 visits/week for a total of 23 visits. A treatment plan based on the FMT clinical reasoning paradigm[43] and the literature on CECS aimed to: 1) decrease subjective symptoms as measured via the NPRS and the LEFS; 2) enhance soft tissue, myofascial, neural-fascial and articular mobility as measured by joint mobility, neural tension, passive and active ROM, and end-feel; 3) training neuromuscular and motor control patterns for efficient running mechanics; and 4) optimizing function while recognizing regional interdependence, as measured by the LEFS and the subject's ability to return to running and cycling without pain. Following the FMT clinical reasoning paradigm,[43] interventions addressed mechanical capacity, neuromuscular function and motor control impairments across the lower quadrant aiming to address all aspects of the movement system. Mechanical capacity was operationally defined as the quality and excursion of movement including mobility of joints (arthrokinematics, osteokinematics, and accessory motions) and soft tissues (skin, muscles, connective tissues, neurovascular structures, and viscera). Neuromuscular function was operationally defined as the neurophysiological ability of synergistic muscles to initiate a contraction with proper strength and endurance for a given task, including the ability to return to a state of muscular relaxation. Finally, motor control was operationally defined as the ability to learn and perform the skillful and efficient assumption, maintenance, modification and control of voluntary movement patterns and postures.[51] This paradigm was followed within each treatment session and throughout the episode of care.

Inherent and unique to functional mobilization is the use of local or regional active movements and graded resisted contractions in three planes of motion designed to engage the barrier and enhance mobility.[43] Also unique to FMT is that immediately following mobilization the therapist seamlessly progresses to the enhancement of neuromuscular function and motor control through aspects of proprioceptive neuromuscular facilitation (PNF) and functional training.[43]

The purpose of the initial treatments was to improve accessory mobility of articular structures and functional excursion of muscles identified to be restricted in the initial examination. It also aimed to enhance the muscles extensibility and ability to expand due to the increased blood flow for proper oxygenation during exertional contractions. A restriction was determined to be present when accessory or physiologic motion was limited and/or when motion presented with a hard end-feel. The treatment emphasized improvement of myofascial mobility and fascial extensibility of the four lower leg compartments through the functional mobilization techniques.[43,52,53] In addition to the extensive focus on mobility of the lower extremities, treatment also addressed mobility of the lumbar spine, sacrum and coccyx as these are believed to be crucial to the function of the lower extremity.[43] The regional interdependence of the upper and lower quadrants was addressed through functional activities aimed at enhancing dynamic core control and strength during functional tasks. Functional mobilization techniques utilized throughout the episode of care include soft tissue mobilization systematically addressing skin, superficial fascia, soft tissue attachments along bony contours and myofascial structures; and joint mobilization through functional mobilization or resistance enhanced manipulation.[43] Changes resulting from these techniques were measured through the re-examination of active and passive joint motion, three-dimensional functional movement patterns, movement in weight bearing and non-weight bearing postures, and the end-feel assessment of accessory motions.[43] See Appendix A for an outline and sequence of interventions used across the episode of care.

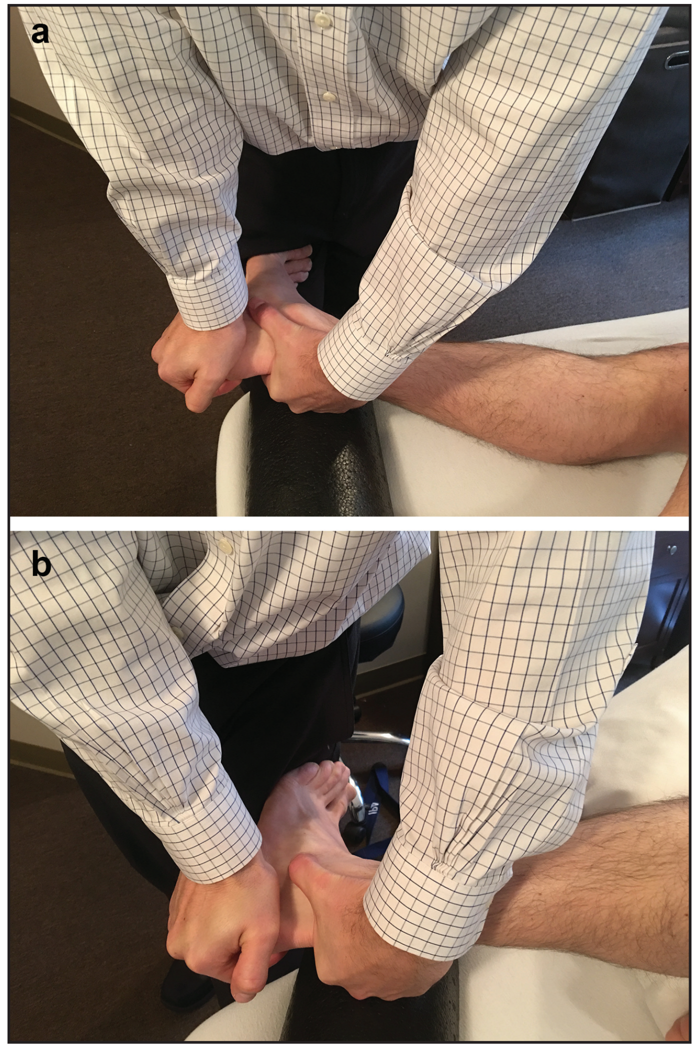

Figure 1. *a. Functional Mobilization of the Calcaneus - Lateral Glide. b. Functional Mobilization of the Calcaneus - Medial Glide*

In the first and second treatment session, focus was placed on the soft tissue and articular mobility of the foot and ankle. Managing mobility of the plantar surface, calcaneus (Figure 1), talus (Figure 2), distal tibial-fibular articulation, interosseous membrane (Figure 3), fibular head, midfoot and forefoot is crucial to improving foot and ankle mobility to allow for proper LE function.[43,52,53] The subject was then given a home exercise program to reinforce mobility gains through single limb stance and closed chain stability through mini-squats. The subject was also instructed to perform the abdominal series (Figure 4) 3x/day to facilitate the activation, strengthening and endurance of core muscles in preparation for gait activities. This series consists of multi-position isometric resistance facilitated by 1) bilateral LE flexion, 2) bilateral LE flexion/adduction, and 3) bilateral LE extension with a neutral position of the lumbar spine. Immediately following functional mobilization techniques, PNF lower extremity flexion/adduction/external rotation and extension/abduction/internal rotation patterns were used to facilitate proper activation of the trunk allowing for adequate proximal stability for distal mobility of the LE (Figure 5). Prolonged holds of end range contractions were utilized to facilitate core muscle function in the trunk while the techniques of combination of isotonics and dynamic reversals were used to enhance coordination of motion in the LE.[54] After the second treatment session the subject reported that his lower legs felt "released for the first time in years" lasting a few days. As the function of local issues in the foot and ankle improved, the focus of treatment shifted to dysfunctions present at the hip and pelvic girdle to address regional interdependence.

Figure 2. *a. Functional Mobilization of the Talus - Lateral Glide. b. Functional Mobilization of the Talus - Posterior Glide.*

Figure 3. *Functional mobilization of the tibial-fibular interosseous membrane*

In the third session, two weeks after the initial evaluation, treatment progressed to focus on articular and soft tissue mobility of the pelvic girdle in an effort to improve postural alignment and enhance standing and gait function.[55-57] Functional mobilization of the lower quadrant was performed to restore symmetry and mobility in the coccyx, sacrum, innominate, lumbar spine and hips.[43,52,53] With improved soft tissue and joint mobility of the lower quadrant, interventions focused on facilitating effective proximal stability for

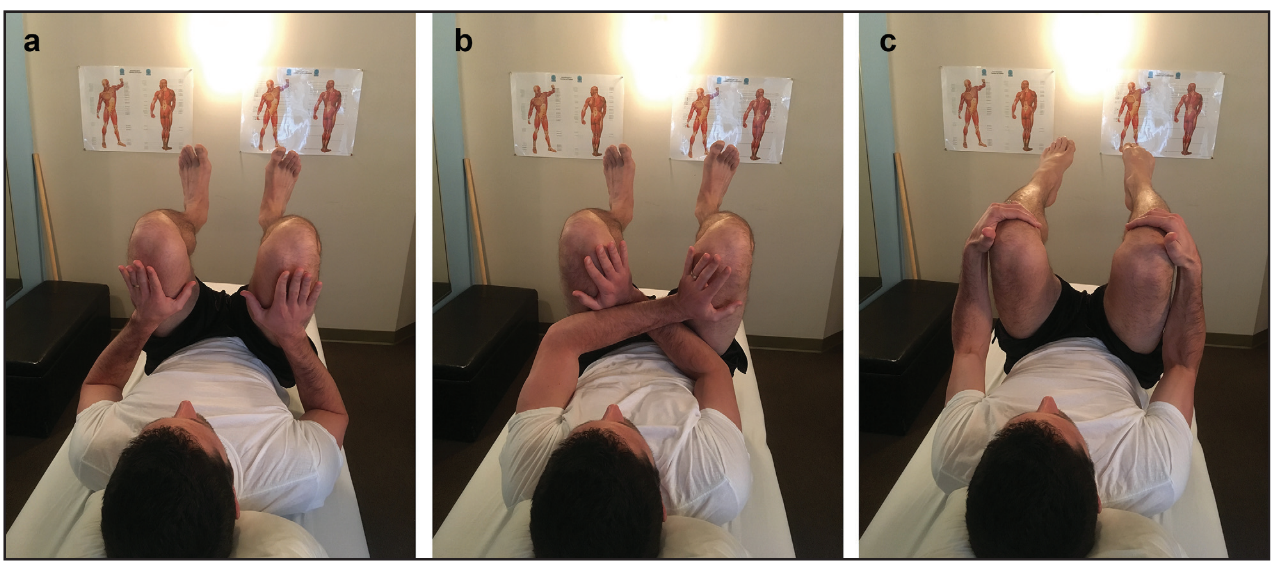

Figure 4a-c. *Abdominal Series: a series of isometric resistance exercises for initiation, strength and endurance of the core muscles. Each position is held for 45 seconds it allowing for irradiation from the hip musculature to the trunk musculature. The whole series is repeated 33-5 times/day for first 2 months and then once/day prior to workouts. a) Use UE's placed on the anterior LEs to resist bilateral hip flexion b) Use UEs placed criss-crossed on the anterior LEs to resist bilateral hip flexion/adduction c) Use UEs placed on the anterior shins to resist bilateral hip extension. Repeat 4a for approximately 10 seconds to conclude the series with bilateral hip flexion*

Figure 5. *a. Resisted Lower Extremity PNF Flexion Patterns (hip flexion, adduction, external rotation with knee flexion and ankle dorsiflexion and inversion). Resistance is applied to all components of the pattern through the range of motion making sure that the core stabilizers are engaged creating a dynamic anchor for the lower extremity motion. The number of repetitions is based on the patient's ability to perform the pattern with proper form.b. Resisted Lower Extremity PNF Extension Patterns (hip extension, abduction, internal rotation with knee extension and ankle plantarflexion and eversion). Resistance is applied to all components of the pattern through the range of motion making sure that the core stabilizers are engaged creating a dynamic anchor for the lower extremity motion. The number of repetitions is based on the patient's ability to perform the pattern with proper form.*

distal mobility during functional activities through PNF patterns. Treatment focused on neuromuscular function for initiation, strength and endurance of LE movements necessary for gait through PNF neuromuscular re-education techniques including

Figure 6. *Ankle Pivot PNF Patterns. The hip and knee are resisted isometrically in the mid-range of the PNF diagonal pattern of flexion/adduction/external rotation and knee flexion while the ankle "pivots" against resistance into concentric dorsiflexion and inversion. The number of repetitions is based on the patient's ability to perform the pattern with proper form.*

pelvis anterior elevation and posterior depression, LE PNF diagonal patterns and ankle pivot patterns (ankle motions performed while the remainder of the LE is maintained in the midrange of the LE PNF diagonal pattern) (Figure 6).[43] Following the third PT visit the subject was able to run three miles without pain despite some tightness in the triceps surae muscle group reporting a sense of increased freedom of movement in the lower back, pelvis and the LEs.

Sessions four through six (weeks two and three of the episode of care) continued to focus on increasing mobility of the myofascial planes in the lower leg compartments through functional mobilization techniques (Figure 7), reinforcing proper gait mechanics, and improving core stability during functional activities through PNF diagonal patterns and techniques for each LE and trunk. Building on the home exercise program the subject was instructed to begin single leg dead lifts for hamstring strength and multi-plane single leg reaches for improved strength and stability of the lower quadrant as it relates to running. After the sixth session the subject reported being able to run four miles without any increased pain. Sessions seven through eleven consisted of progressing single leg strengthening and core exercises, mobilization of the gastrocnemius and soleus for increased muscle play (Figure 8) and continued functional mobilization

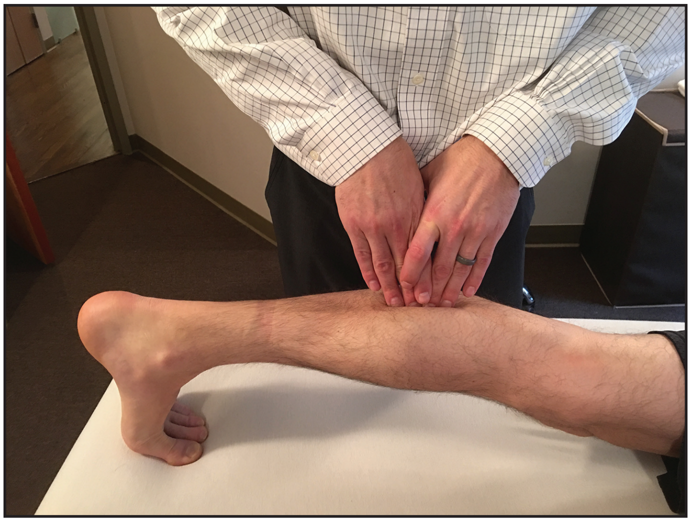

Figure 7. *Functional Mobilization of the Deep Posterior Compartment of the Lower Extremity. The patient actively flexes and extends the knee while a mobilization force is applied to the posterior compartment of the lower leg.*

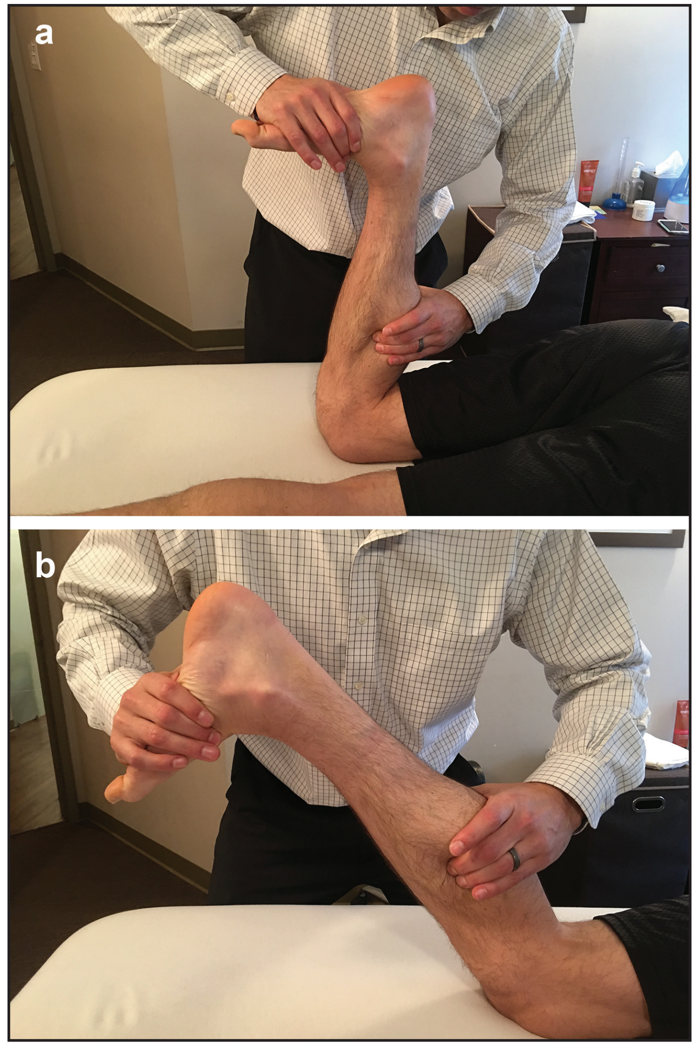

Figure 8. *Functional Mobilization of the Gastrocnemius/Soleus. The therapist flexes the patient's knee and grasps the gastrocnemius-soleus muscles (a). While maintaining a posterior pull on the gastrocnemius-soleus muscles the therapist dorsiflexes the patient's ankle and extends the knee (b).*

of the myofascial compartments of bilateral LE. By the ninth session the subject ran six miles reporting some soreness that improved significantly following the run. After eight weeks of FMT interventions the subject reported running six miles at 8.0 mph pace without any pain and feeling only tightness when stretching the plantarflexors after the run. PT was reduced to one visit/week focusing on continuing functional mobilization of the lower legs as deemed necessary in each session, general LE strength training and running gait training to a midfoot landing close to center of mass strategy. The subject was guided on cadence manipulation and corrective instruction to assist in transitioning the position of foot contact during running. The focus was to promote a more vertical tibia at foot strike minimizing braking forces and increasing acceleration.[58-60] This position of the tibia, coupled with a cadence of 90 strides per minute, has been shown to reduce the impact of ground reaction forces at foot strike decreasing the incidence of injury and CECS.[9,39,61] In addition the subject's home exercise program included isometric high stepping against a wall (Figure 9 shows this exercise being performed against the therapist) facilitating maximal output of the hip extensors/abductors in a weight bearing position for improved strength and stability during push-off .[62] At 12 weeks the subject reported having no pain pre- or post-running and was able to return to training for an Olympic triathlon.

OUTCOME

The subject was seen for a total of 23 visits over three and a half months. At the time of discharge the subject had returned to running and training pain free with an 18-point improvement in the LEFS to 80/80, surpassing the 9-point MCID and the MDC. Goniometric measurements of ankle passive ROM have been shown to have strong intra-tester reliability ($ICC_{2,3}$ = 0.85-0.96) and to have an MDC of 3.7°-3.8°.[63] Gains in all ankle passive ROM surpassed the established MDC.[63] The subject also demonstrated increased strength across the LE musculature. While no MCID or MDC have been established for strength

Figure 9. *Resisted High Step. The therapist applies appropriate resistance to the stepping leg while allowing the patient to push forward with the stance leg as if taking a step forward.*

testing, manual muscle testing is a valid and reliable clinical test of muscle strength.[64]

Repeat ICP measures on the left LE were re-examined four months following discharge. Resting and post-exercise measures (treadmill with incline of 5% and running pace of 7 mph) were taken. All ICP measures were within normal limits at rest and one-minute post exercise (Table 1). The subject continued to train rigorously and reported a global rating of change (GRC) of +6 on a 15-point scale indicating that the subject was a 'great deal better'. The GRC is considered a valid and reliable subjective measure of clinical improvement.[65] Six months following discharge the subject completed an Olympic Triathlon without any pain. At a three-year follow up the subject presented with 0/10 pain at rest, 0/10 pain with no impact activity, and minimal pain (2/10) with high impact activity that did not cause cessation of activity and returned to 0/10 with rest.

DISCUSSION

CECS is a painful and often misdiagnosed condition causing significant lower leg pain in athletes, most commonly in runners.[6] While PT is commonly attempted in the non-operative management of CECS, surgical fasciotomy of the involved compartment remains the standard approach to treatment given its high success rate in getting athletes back to running.[1,8,10,30,31] While 80% successful, surgical intervention carries the inherent risk of all invasive procedures including infection, hemorrhage, nerve damage, soft tissue scarring, and sensory deficits among others.[10,11,30,31,33] This case report presents the application of FMT, a comprehensive approach to physical therapy, in the treatment of a competitive athlete diagnosed with CECS. The systematic clinical management of mechanical, neuromuscular and motor control impairments across the lower quadrant, while considering principles of regional interdependence,[66,67] provided this subject with enhanced functional capacity and a return to competitive running pain free without the risks and costs of surgical intervention.

While the source of pain in CECS may be the increased intra-compartmental pressures in the LE, it seems possible that this may be caused by mechanical dysfunctions in any aspect of the lower quadrant including the lumbar spine, pelvic girdle, hip, knee, foot, or ankle. Changes in landing patterns (forefoot, midfoot or rearfoot) along with the location of the strike relative to the center of mass have been shown to affect how ground reaction and impact transient forces (a force occurring at the beginning of the ground reaction force that is generated at heel strike)[61] translate from the foot to the lumbar spine.[68] It is reasonable to infer that a dysfunction anywhere along this continuum may affect how the foot functions during running possibly leading to soft tissue and fascial tension in the LE.[67,68] This possibility supports the hypothesis that the clinical management of CECS must address all aspects of the movement system across the lower quadrant.

The subject described in this case reported significant improvements in the feeling of tightness and pain in the LE after only two sessions where the treatment focused on the mobilization of mechanical restrictions across the lower extremities. This immediate relief in pain did not translate into improved ability to run without pain until all impairments in the movement system were addressed across the lower quadrant. Due to the limitations inherent in a case report, it is not possible to discern which aspect of this comprehensive approach had the greatest influence or allowed the subject's successful return to running. The authors hypothesize that addressing any one aspect of the movement system may provide temporary and partial relief while a comprehensive approach to alleviating impairments at all levels of the movement system across the lower quadrant would lead to the long-term return to participation in all functional activities pain free. This hypothesis is supported by a recent systematic review on the conservative management of CECS.[40] The use of massage in one case series resulted in improvement in pain but follow up was only five weeks when the participants had not yet returned to running.[40,41] Four researchers assessed a change in gait or running pattern and determined it to be successful in allowing a return to running but the longest follow-up was only one year.[9,39,69,70]

CONCLUSIONS

The resolution of impairments and movement dysfunctions throughout the kinetic chain using the FMT approach, against the backdrop of previous failed attempts at PT, may have played a role in the subject's return to competitive running and all functional activities without pain. The subject continued to do so three years post intervention. An understanding of the movement system as a complex system comprising of anatomic and physiologic structures and functions[42] supports the need for PTs to look beyond local and specific tissue dysfunction and address all aspects of the movement system. Future clinical trials exploring FMT as a systematic approach to the management of CECS are indicated.

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APPENDIX A. *Interventions Across the Episode of Care*

Rx Session (*Week #*)	Interventions for Mechanical Capacity Impairments	Interventions for Neuromuscular Function Impairments	Interventions for Motor Control Impairments
1 (exam) & 2 *Week 1*	- FM to superficial and deep soft tissue in the plantar surface of the rearfoot, midfoot and forefoot - FM to accessory mobility of the calcaneus into medial/lateral glide and gapping (Figure 1a & 1b) - FM to accessory mobility of the talus into anterior/posterior and medial/lateral glide (Figure 2a & 2b) - FM to accessory mobility of the navicular into posterior/inferior glide during a closed chain knee mini squat - FM to tibia/fibula interosseus membrane (Figure 3)	- Neuromuscular re-education for active and resisted ankle, knee and hip motions through PNF lower extremity diagonal patterns in supine and sidelying (hip flexion/abduction/internal rotation, hip extension/adduction/external rotation, hip flexion/adduction/external rotation, hip extension/abduction/internal rotation) (Figure 5a & 5b) - Abdominal series Figure 4a-c)	- Single limb stance with contralateral high stepping - Closed chain stabilization activities through mini-squats
3 *Week 2*	- FM to soft tissues and soft tissue attachment to bony contours across the lower lumbar spine, sacrum, innominate and coccyx - FM to sacral-coccygeal joint into bilateral rotation and lateral flexion - FM to right sacrum base P/A for form closure - FM to right innominate for inferior depression - FM to bilateral hip inferior glide	- PNF bilateral pelvis anterior elevation and posterior depression - PNF LE flexion and extension patterns (Figure 5a & 5b) - PNF ankle pivot patterns of dorsiflexion/inversion and dorsiflexion/eversion with a fixed heel (Figure 6)	- Single limb stance with contralateral high stepping (Figure 9) - Cross extension high stepping against a wall for strengthening in new mobility ranges - Beginning to transition to mid-foot strike for running
4 *Week 2*	- FM to lumbar spine for P/A and left rotation of L5-S1 - FM to right innominate for internal, external and posterior rotation - FM to anterior and posterior glide of distal tibia and fibula - FM to anterior, lateral, superficial posterior and deep posterior compartments (Figure 7)	- PNF anterior elevation and posterior depression pelvic patterns - PNF lower extremity diagonal patterns (Figure 5a & 5b)	- PNF gait training with a focus on weight shift and weight acceptance onto stance lower extremity
5 & 6 *Week 3*	- FM to right innominate for internal, external and posterior rotation - FM to lumbar spine for P/A and left rotation of L5-S1 - FM to tibia/fibula interosseus membrane (Figure 3) - FM to anterior, lateral, superficial posterior and deep posterior compartments (Figure 7)	- PNF trunk patterns - PNF lower extremity diagonal patterns (Figure 5a & 5b)	- Single leg dead lifts - Multi-plane single leg reaches - PNF gait training with resistance to pelvis anterior elevation

APPENDIX A. *Interventions Across the Episode of Care (continued)*

Rx Session (*Week #*)	Interventions for Mechanical Capacity Impairments	Interventions for Neuromuscular Function Impairments	Interventions for Motor Control Impairments
7 - 11 *Week 4-7*	- FM to accessory mobility of the calcaneus into medial/lateral glide and gapping (Figure 1a & 1b) - FM to accessory mobility of the talus into anterior/posterior and medial/lateral glide in closed chain (figure 2a & 2b) - FM to proximal fibular head A/P glide - FM to tibialis posterior - FM to anterior, lateral, superficial posterior and deep posterior compartments (Figure 7) - FM to accessory mobility of lower lumbar spine for lumbar extension	- PNF trunk patterns - PNF lower extremity diagonal patterns (Figure 5a & 5b) - PNF ankle pivot patterns of dorsiflexion/inversio n and dorsiflexion/eversion with a fixed heel (Figure 6) - Segmental lower trunk rotation with facilitation and emphasis on segmental control	- Single limb stance strengthening through resisted high stepping (Figure 9) - Core strengthening through resistance to bilateral lower extremity flexion in supine - Lower trunk rotation from hooklying - Running mechanics with focus on continuing the transition to mid-foot strike
12 - 18 *Week 8-11*	- FM to accessory mobility of the sacrum in form closure - FM to iliopsoas, rectus femoris, vastus medialis and vastus lateralis for improved hip extension and knee flexion range of motion - FM to accessory mobility of the talus into posterior and anterior glide for dorsiflexion and plantarflexion in closed chain, half-kneeling - FM to accessory mobility of anterior and posterior glide of distal tibia and fibula in closed chain, half-kneeling - FM to accessory mobility of anterior and posterior glide of fibular head in closed chain, squatting - FM to accessory mobility of superior glide of navicular on talus in closed chain, hooklying - FM to gastrocnemius and soleus for improved muscle play (Figure 8a & 8b)	- PNF anterior elevation and posterior depression pelvic patterns - PNF lower extremity diagonal patterns (Figure 5a & 5b) - PNF ankle pivot patterns of dorsiflexion/inversio n and dorsiflexion/eversion with a fixed heel (Figure 6) - Reciprocal scapular and pelvic PNF patterns for improved dynamic control and reciprocation during gait and running	- PNF gait training with resistance to pelvis anterior elevation - Resisted high step gait - Front/back & side/side mechanics drill - Running mechanics with a focus mid-foot strike

APPENDIX A. *Interventions Across the Episode of Care (continued)*

Rx Session (*Week #*)	Interventions for Mechanical Capacity Impairments	Interventions for Neuromuscular Function Impairments	Interventions for Motor Control Impairments
19-23 *Week 12-15*	- FM to gastrocnemius and soleus for improved muscle play (Figure 8a & 8b) - FM to anterior, lateral, superficial posterior and deep posterior compartments (Figure 7)	- PNF anterior elevation and posterior depression pelvic PNF patterns - PNF lower extremity diagonal patterns (Figure 5a & 5b) - PNF ankle pivot patterns of dorsiflexion/inversion and dorsiflexion/eversion with a fixed heel (Figure 6) - Reciprocal scapula and pelvic patterns for improved dynamic control and reciprocation during gait and running	- PNF gait training with resistance to pelvis anterior elevation - Resisted high step gait (Figure 9) - Front/back mechanics drill - Running mechanics with a focus mid-foot strike

*All neuromuscular function activities were performed with the techniques of prolonged isometric holds at the end of a new range and combination of isotonics using appropriate resistance throughout the available range of motion.[50]

Abbreviations: FM, functional mobilization; PNF, proprioceptive neuromuscular facilitation;